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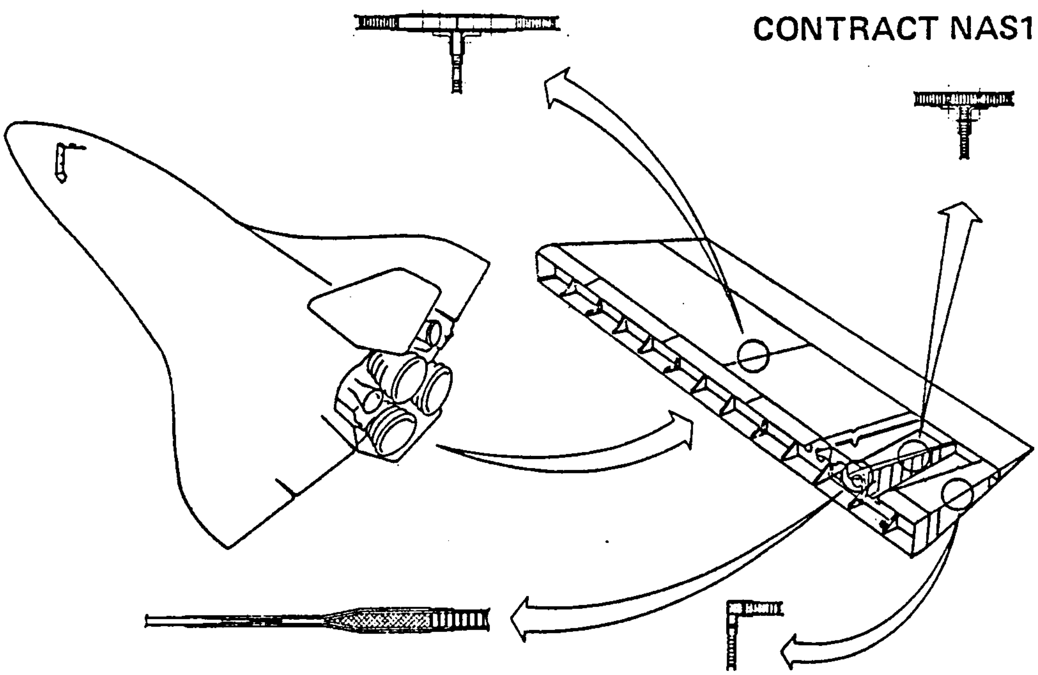
DESIGN, FABRICATION AND TEST OF GRAPHITE/POLYIMIDE COMPOSITE JOINTS AND ATTACHMENTS FOR ADVANCED AEROSPACE VEHICLES

QUARTERLY TECHNICAL PROGRESS REPORT NO. 5
COVERING THE PERIOD FROM

FEBRUARY 1, 1980 THROUGH APRIL 30, 1980

CONTRACT NAS1-15644



PREPARED FOR
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER
HAMPTON, VIRGINIA 23665

MAY 19, 1980

BOEING AEROSPACE COMPANY
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Seattle, Washington 98124

N81-16042#

FOREWORD

This report summarizes the work performed by the Boeing Aerospace Company (BAC) under NASA Contract NAS1-15644 during the period February 1, 1980, through April 30, 1980.

This program is sponsored by the National Aeronautics and Space Administration, Langley Research Center (NASA/LaRC), Hampton, Virginia. Dr. Paul A. Cooper is the Technical Representative for NASA/LaRC.

Performance of this contract is by Engineering Technology personnel of BAC. Mr. J. L. Arnquist is the Program Manager and Mr. D. E. Skoumal is the Technical Leader.

The following Boeing personnel were principal contributors to the program during this reporting period: D. L. Barclay, Design; J. B. Cushman, Analysis; S. G. Hill and C. H. Sheppard, Materials and Processes; R. E. Jones and S. M. Williams, Finite Element Analysis.

TABLE OF CONTENTS

SUMMARY

This document reports on activities from February 1, 1980, through April 30, 1980, of an experimental program to develop several types of graphite/polyimide (GR/PI) bonded and bolted joints. The program consists of two concurrent tasks. TASK 1 is concerned with design and test of specific built-up attachments, while TASK 2 evaluates standard and advanced bonded joint concepts. The purpose is to develop a data base for the design and analysis of advanced composite joints for use at elevated temperatures [561K (550°F)]. The objectives are to identify and evaluate design concepts for specific joining applications and to identify the fundamental parameters controlling the static strength characteristics of such joints. The results from these tasks will provide the data necessary to design and build GR/PI lightly loaded flight components for advanced space transportation systems and high speed aircraft.

During this reporting period, principal program activities dealt with the literature survey, design of joint concepts, assessment of GR/PI material quality, fabrication of test panels and specimens, and small specimen testing. Bonded and bolted designs are presented for each of the four major attachment types. Quality Control data are presented for prepreg Lots 2W4651 and 3W2020. Preliminary design allowables test results for tension tests of $0°_{16}$, $90°_{30}$, $(0,\pm45,90)_{4S}$ and $\pm45°_{8S}$ laminates, and compression tests of $(90,\pm45,0)_{4S}$ laminates are also presented.

SECTION 1.0

INTRODUCTION

This is the 5th quarterly report covering results of activity during the period February 1, 1980, through April 30, 1980.

The purpose of this program is to provide a data base for the design of advanced composite joints useful for service at elevated temperatures [561K (550°F)]. The current epoxy-matrix composite technology in joint and attachment design will be extended to include polyimide-matrix composites. This will provide data necessary to build graphite/polyimide (GR/PI) lightly loaded flight components for advanced space transportation systems and high speed aircraft. The objectives of this contract are twofold: first, to identify and evaluate design concepts for specific joining applications of built-up attachments which could be used at rib-skin and spar-skin interfaces; second, to explore advanced concepts for joining simple composite-composite and composite-metallic structural elements, identify the fundamental parameters controlling the static strength characteristics of such joints, and compile data for design, manufacture, and test of efficient structural joints using the GR/PI material system.

The major technical activities follow two paths concurrently. The TASK 1 effort is concerned with design and test of specific built-up attachments while the TASK 2 work evaluates standard and advanced bonded joint concepts.

The generic joint concepts to be developed under TASK 1 are shown in Figure 1-1. The total program is scheduled over a period of 27 months as shown in Figure 1-2.

In TASK 1.1, several concepts were designed and analyzed for each bonded and each bolted attachment type and reported in reference 1. Concurrent with this task a series of design allowable and small specimen tests are being conducted under TASK 1.2. The analytical results of TASK 1.1 and the design data from TASK 1.2 will allow a selection of the most promising bonded and bolted concepts.

In TASK 1.3, a maximum of two of the most promising concepts for each joint type will be fabricated, tested and evaluated. The evaluation will yield

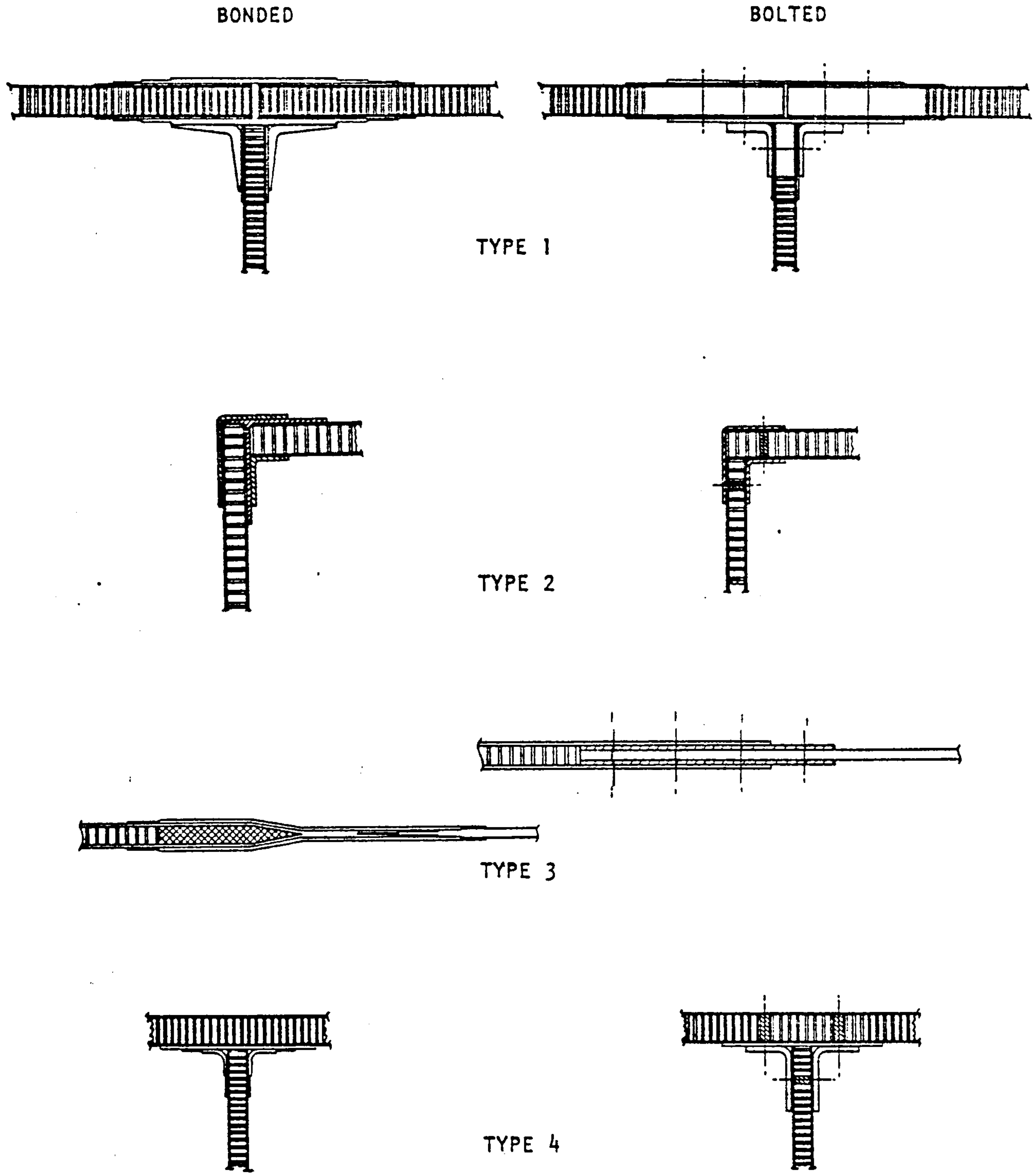
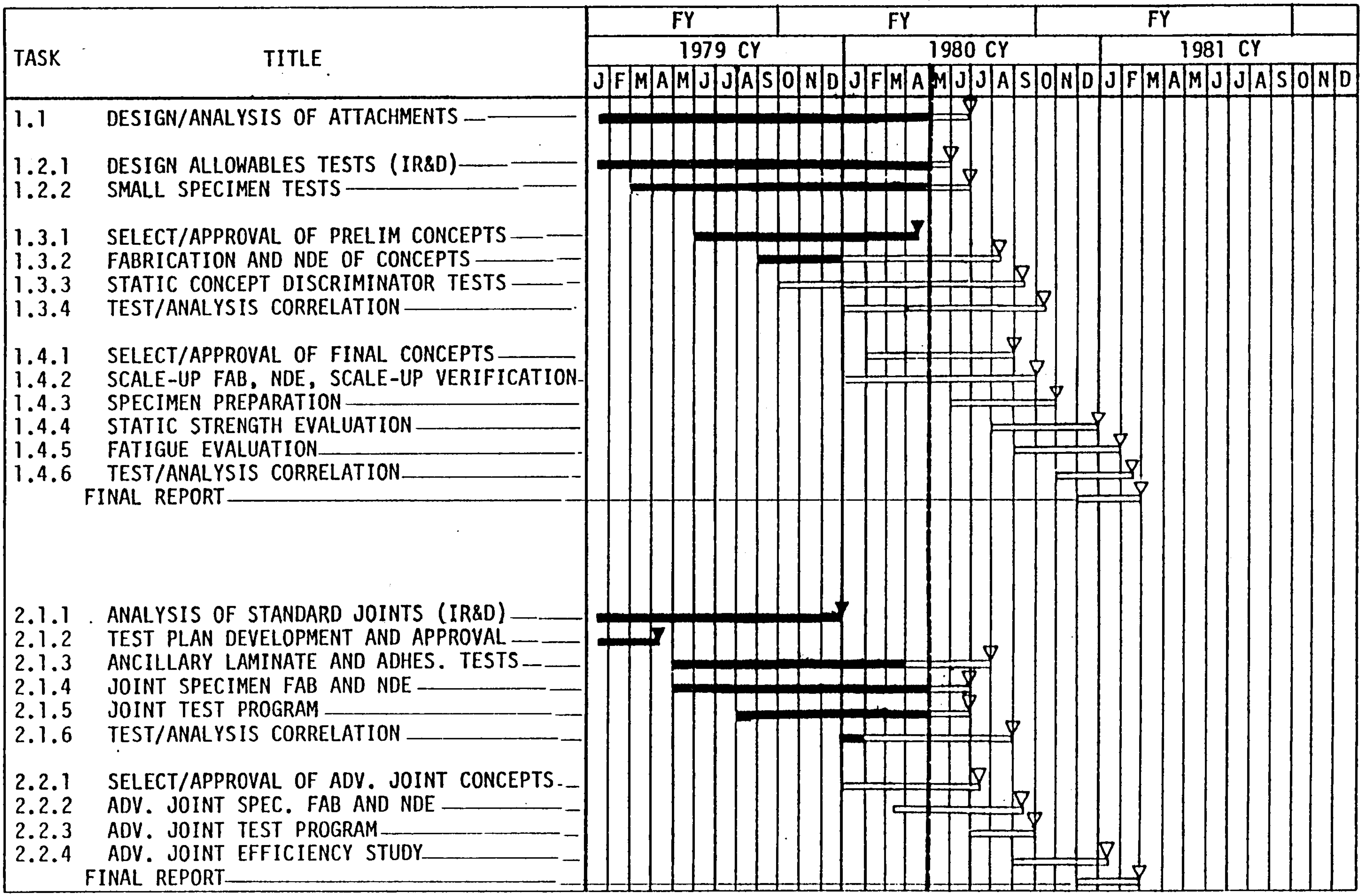


Figure 1-1: Generic Joint Concepts for 4 Attachment Types

NASA CONTRACT NAS1-15644

DESIGN, FABRICATION AND TEST OF GRAPHITE/POLYIMIDE COMPOSITE JOINTS AND ATTACHMENTS FOR ADVANCED AEROSPACE VEHICLES



LEGEND

STATUS AS OF: 4/30/80

▼ ENDING DATE

◊ REVISED ENDING DATE

Figure 1-2: Master Program Schedule

the preferred joint concepts and will be based on weight efficiency, ease of fabrication, detail part count, inspectability and predicted fatigue behavior.

Finally, eight joint concepts (2 of each joint type) will be fabricated in TASK 1.4 on a scaled-up manufacturing basis to assure that reliable attachments can be fabricated for full-scale components. A series of static tests will be performed on specimens cut from the scaled-up attachments to verify the validity of the manufacturing process. Additional specimens will be thermally conditioned and tested in a series of static and fatigue tests. Test results will be compared with the analytical predictions to select final attachment concepts and design/analysis procedures.

The TASK 2 activity will establish a limited data base that will describe the influence of variations in basic design parameters on the static strength and failure modes of GR/PI bonded composite joints over a 116K to 561K (-250°F to 550°F) temperature range. The primary objectives of this research are to provide data useful for evaluation of standard bonded joint concepts and design procedures, to provide the designer with increased confidence in the use of bonded high-performance composite structures at elevated temperature, and to evaluate possible modifications to the standard joint concepts for improved efficiency.

To accomplish these objectives, activity under TASK 2.1 will consist of design, fabrication, and static test of several classes of composite-to-composite and composite-to-metallic bonded joints including single-and-double-lap joints and step-lap joints. Test parameters will include lap length, adherend stiffness and stacking sequence at room and elevated temperatures. Toward the latter part of this program, under TASK 2.2., a selection will be made of advanced lap joint concepts which show promise of improving joint efficiency. Possible concepts are pre-formed adherends, mixed adhesive systems, and lap edge clamping. These concepts will be added to the static strength test program and the results compared with the results from the standard joint tests.

This report summarizes the literature survey, presents joint concepts selected in TASK 1.1 and presents preliminary results of design allowables and small specimen testing completed during this reporting period.

SECTION 2.0
TASK 1 ATTACHMENTS

2.1 TASK 1.1 - Design and Analysis of Attachments

This section discusses the results achieved during this reporting period on the literature survey and on design and analysis of attachments.

2.1.1 Literature Survey

A comprehensive literature search was initiated at the beginning of the program to compile applicable experimental data and analyses concerned with the processing control, properties, and fabrication of GR/PI composite materials. In addition, the search was focused on design/analysis and evaluation of test data of bonded and bolted composite attachments.

Additional literature which has been reviewed and evaluated during this reporting period is listed in References 2 through 4 and is summarized below.

Reference 2 presents results of testing conducted to evaluate the increase in bolted joint efficiency due to laminate tailoring. A soft strip of $\pm 45°$ plies (low modulus) is installed along the bolt line parallel to the load direction. Bolt load is transferred by shear to adjacent stiffer (high modulus) 0° primary load carrying plies. Tests were conducted on single and multiple fastener joints and on full scale components. Tailored laminates provided a 24 percent increase in weight efficiency, and a 62 percent increase in axial strain level as compared to non-tailored laminates.

Finite element analyses of an aluminum symmetric bonded doubler are presented in Reference 3. Analyses investigate the stress distribution through the adhesive thickness. Results show large variations in all stresses through the adhesive thickness in a region close to the adhesive edge. Shear and lateral normal stresses were approximately uniform through the adhesive thickness in the middle 98% of the bond length. Axial normal stresses were uniform along the middle 98% of the bond length, but varied linearly through the adhesive thickness. Peaking of the adhesive stresses near the doubler edge are the key items when considering failure mechanisms.

Reference 4 presents test results of bolted joints and bonded scarf joints of glass-epoxy composite adherends. Laminates tested were unidirectional (0°), fabric, cross-ply and (0,±60°). Single and three-bolt joints with varying bolt torques and scarf joints with 25 mm (1.0 in.) to 127 mm (5.0 in.) lap lengths were investigated. Increasing the bolt torque from 40% of maximum to 80% of maximum produced significant increases in joint efficiency. Maximum efficiency (42%) of a 25 mm (1.0 in.) scarf joint was obtained with a (0,±60) adherend while the maximum efficiency (76%) of a 127 mm (5.0 in.) scarf joint was obtained with woven fabric adherends.

The stress distribution, in both the adhesive and in the adjacent lamina, appears to be the key to monitoring failure initiation in bonded composite joints. Although Reference 3 has reasonable experimental verification of normalized shear stress, this was an aluminum/aluminum bonded specimen. A similar composite system would be affected not only by through-the-thickness adhesive stress variations but also more pronounced non-uniformities caused by lamina stacking sequence, wider CTE differences between the composite adherend and the adhesive layer, as well as lateral stress components. These all contribute to local principal stresses that are difficult if not impossible to accurately measure and/or model in the area adjacent to a free edge.

2.1.2 Design and Analysis

The design/analysis procedure used to develop the joint designs is shown in Figure 2-1 which illustrates the interaction between design, analysis and test. Shaded areas identify approximate percent completion.

During this reporting period additional design and analysis was conducted to select joints for the static discriminator tests. Results of the small specimen tests, although incomplete at this writing, have been utilized to size and proportion pad-up details. Further refinement will be accomplished after all small specimen and design allowable results are reviewed. In the meantime, the most promising concepts have been selected as shown in Figures 2-2 through 2-9. Processing and assembly sequencing are being planned with attention given to methods that would be used to manufacture full-scale joints and close-outs.

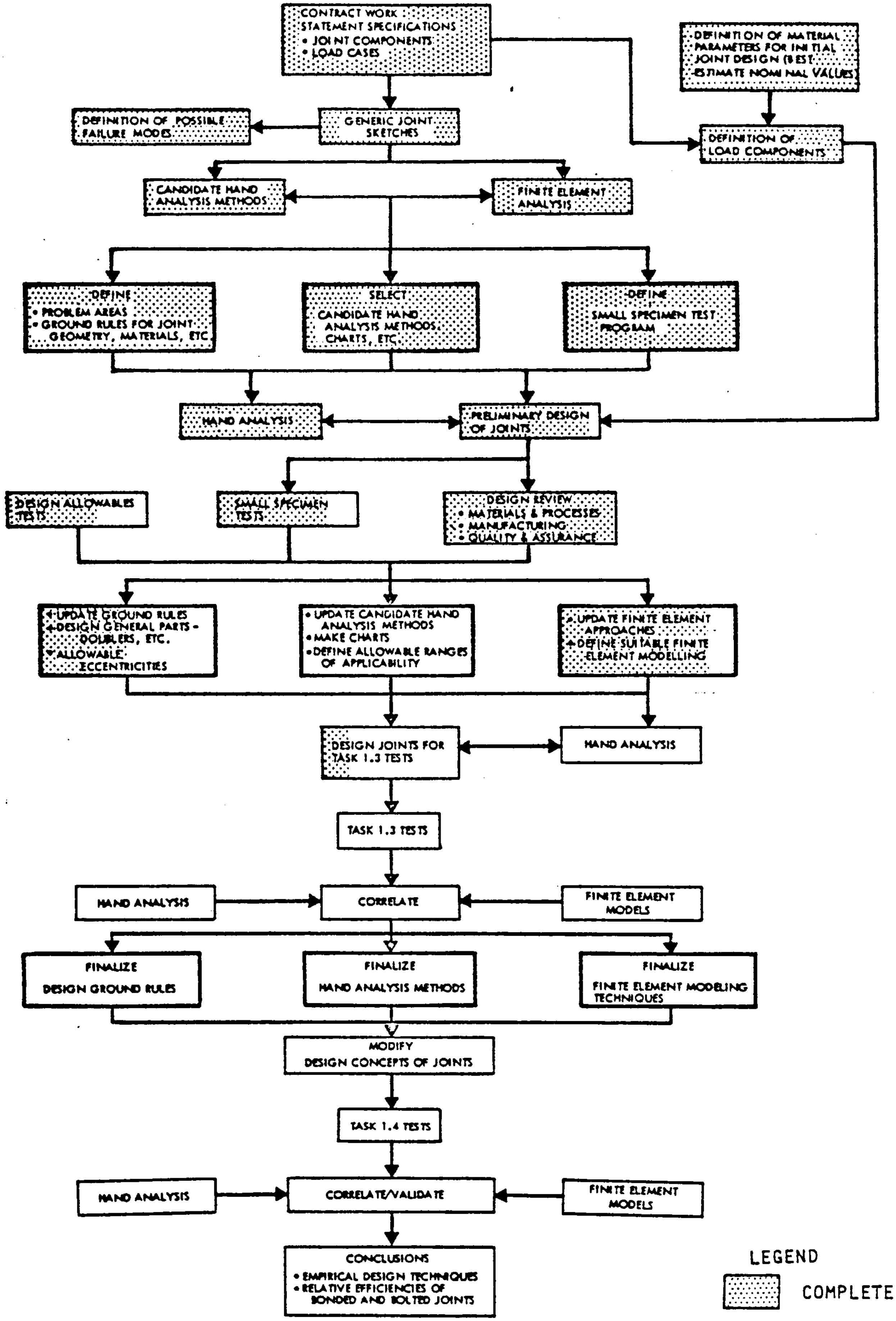


Figure 2-1: Task 1 Design/Analysis/Test Flow Diagram

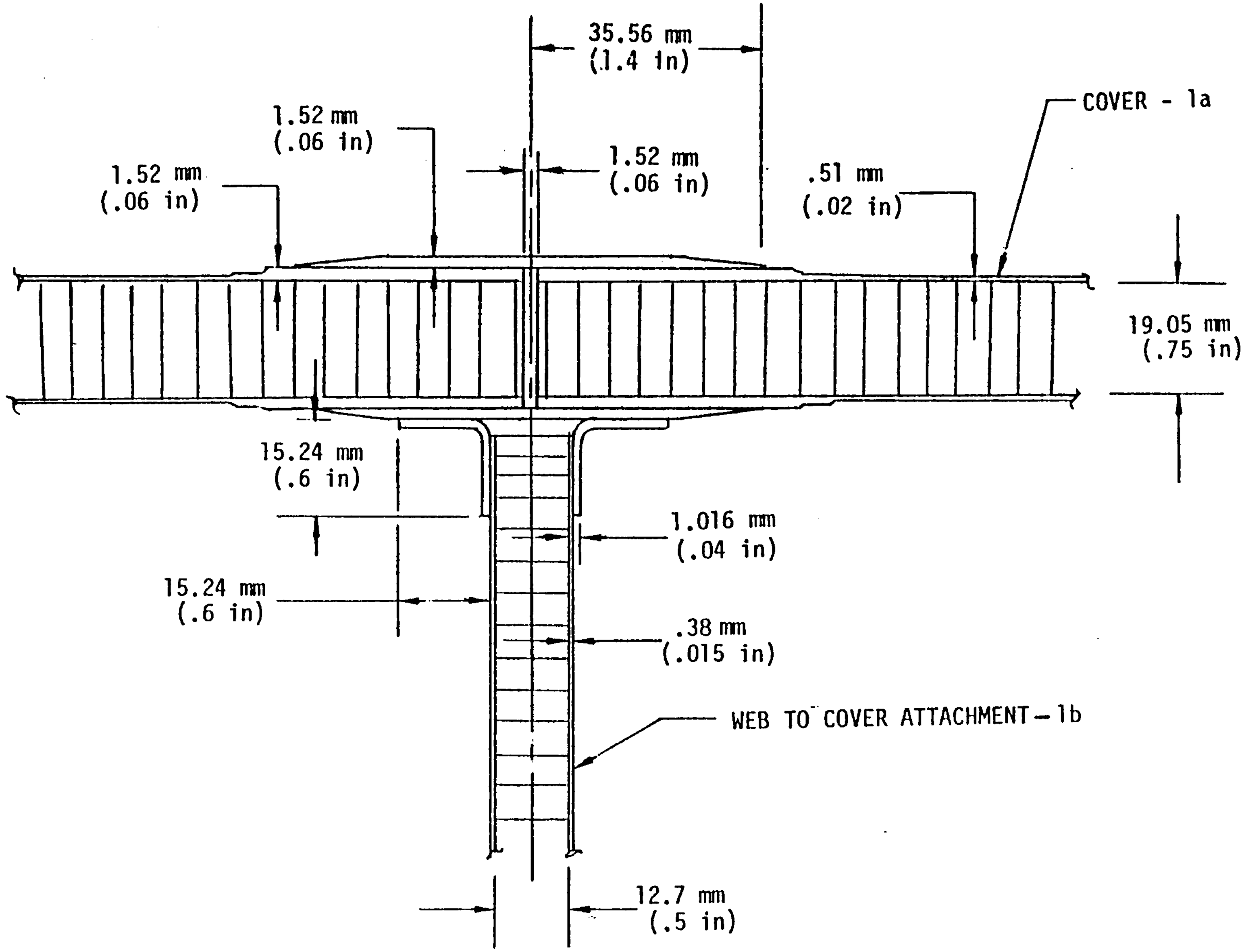


FIGURE 2-2 Type 1 Bonded Joint Concept

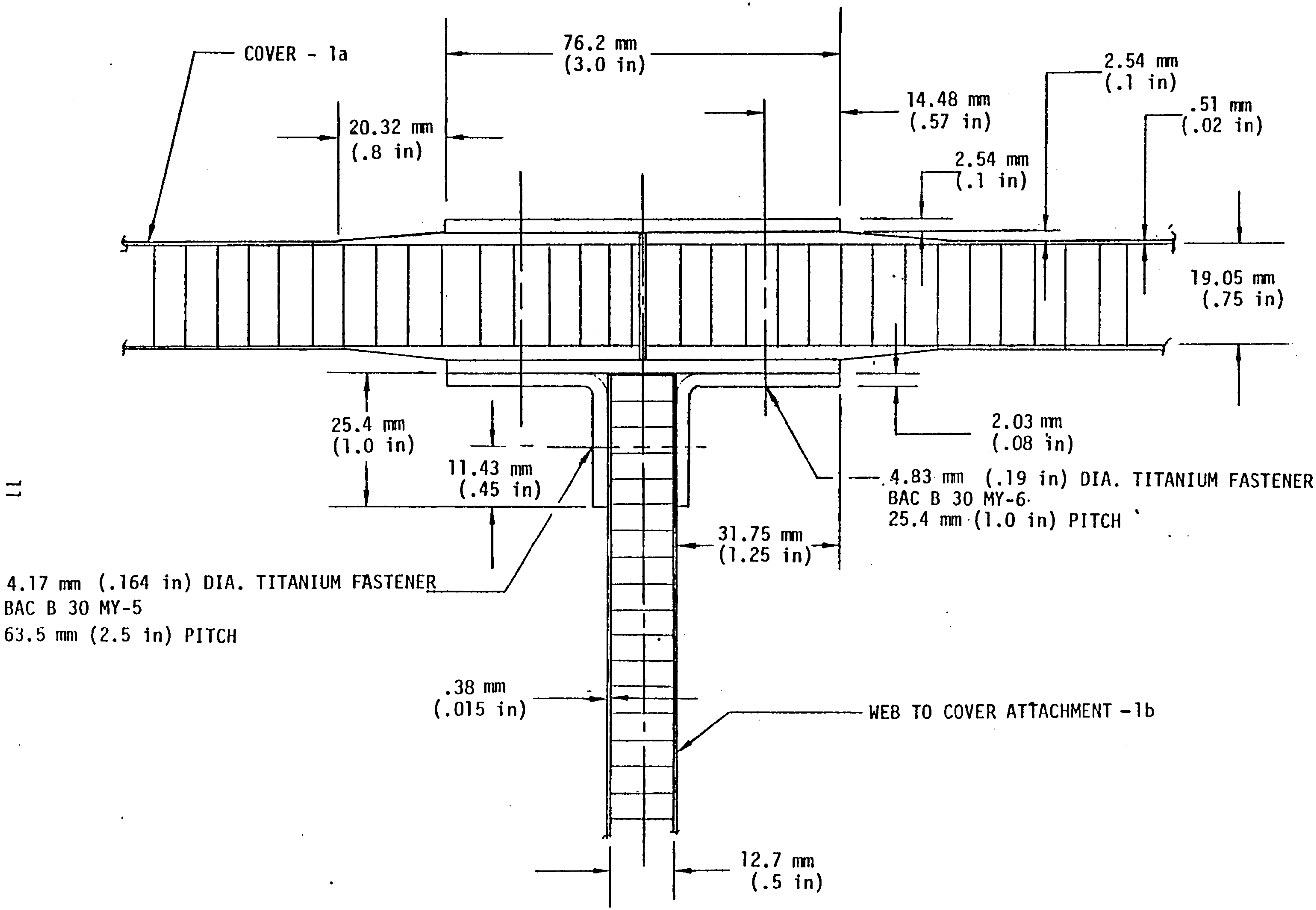


FIGURE 2-3 Type 1 Bolted Joint Concept

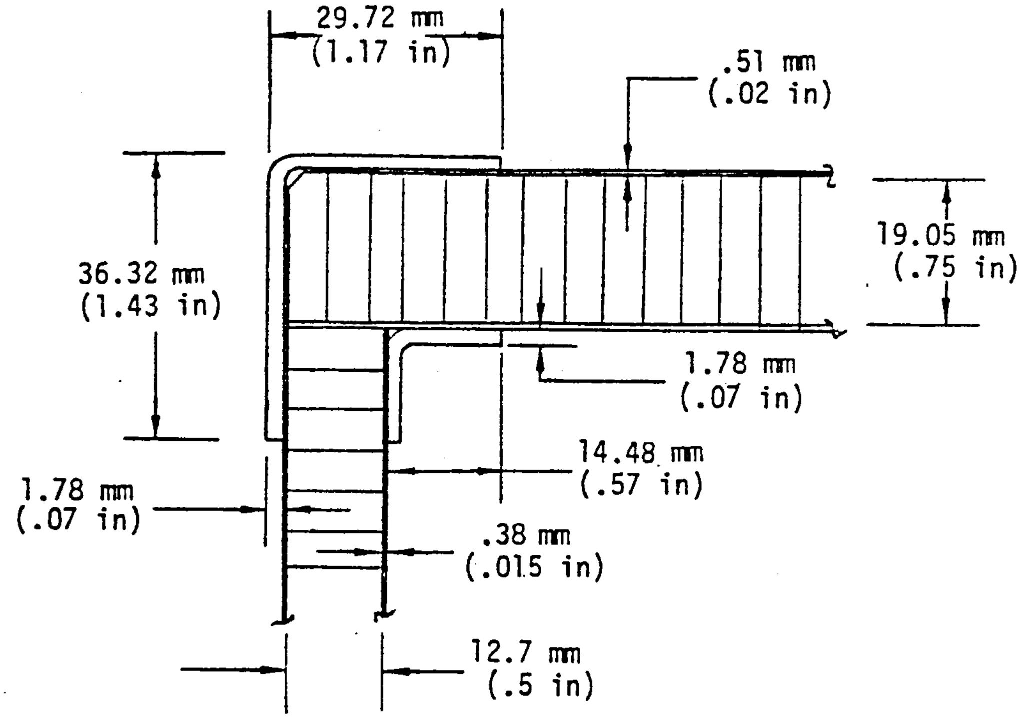


FIGURE 2-4 Type 2 Bonded Joint Concept

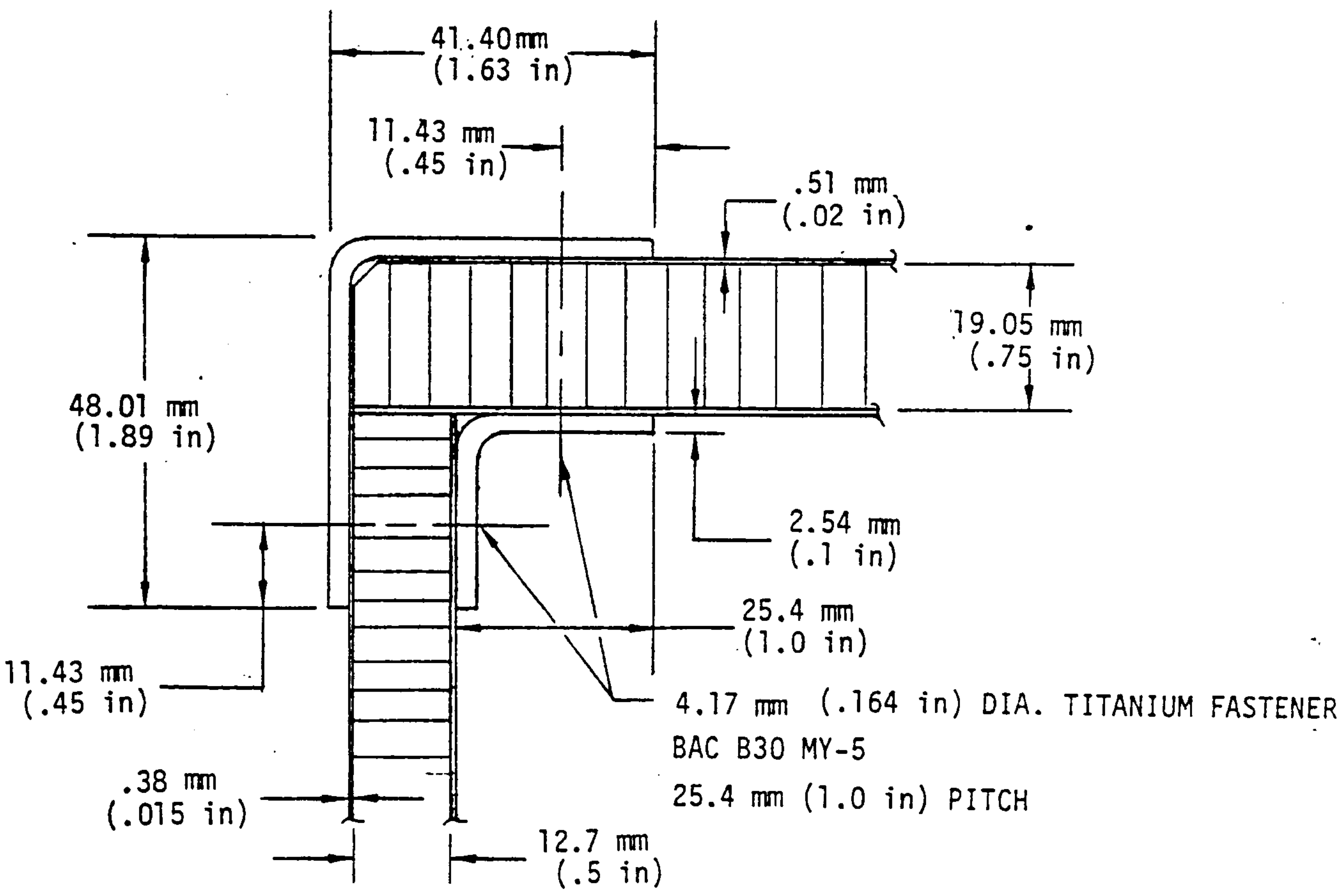


FIGURE 2-5 Type 2 Bolted Joint Concept

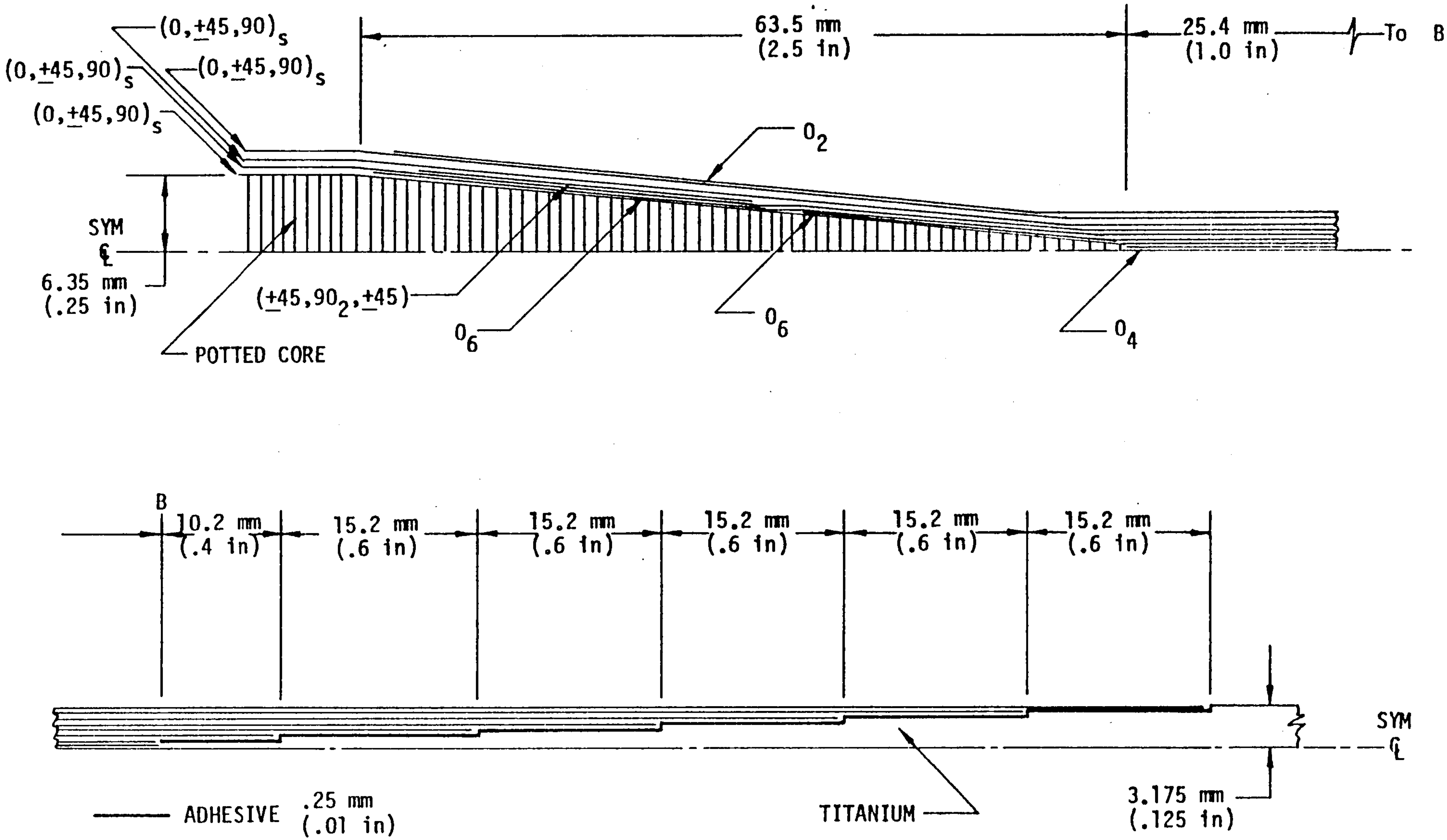
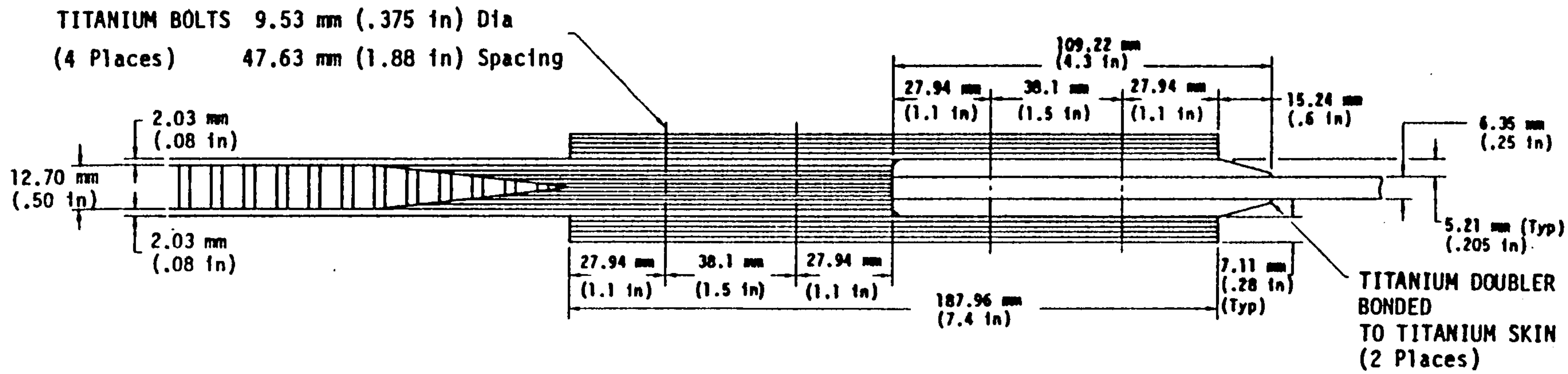


Figure 2-6: Type 3 Bonded Joint Concept



- o N_x is 2.10 MN/m (12,000 lb/in)
- o UNCERTAINTIES
  - Load Distribution
  - Honeycomb Closeout
  - Material Properties

FIGURE 2-7 Type 3 Bolted Joint Concept

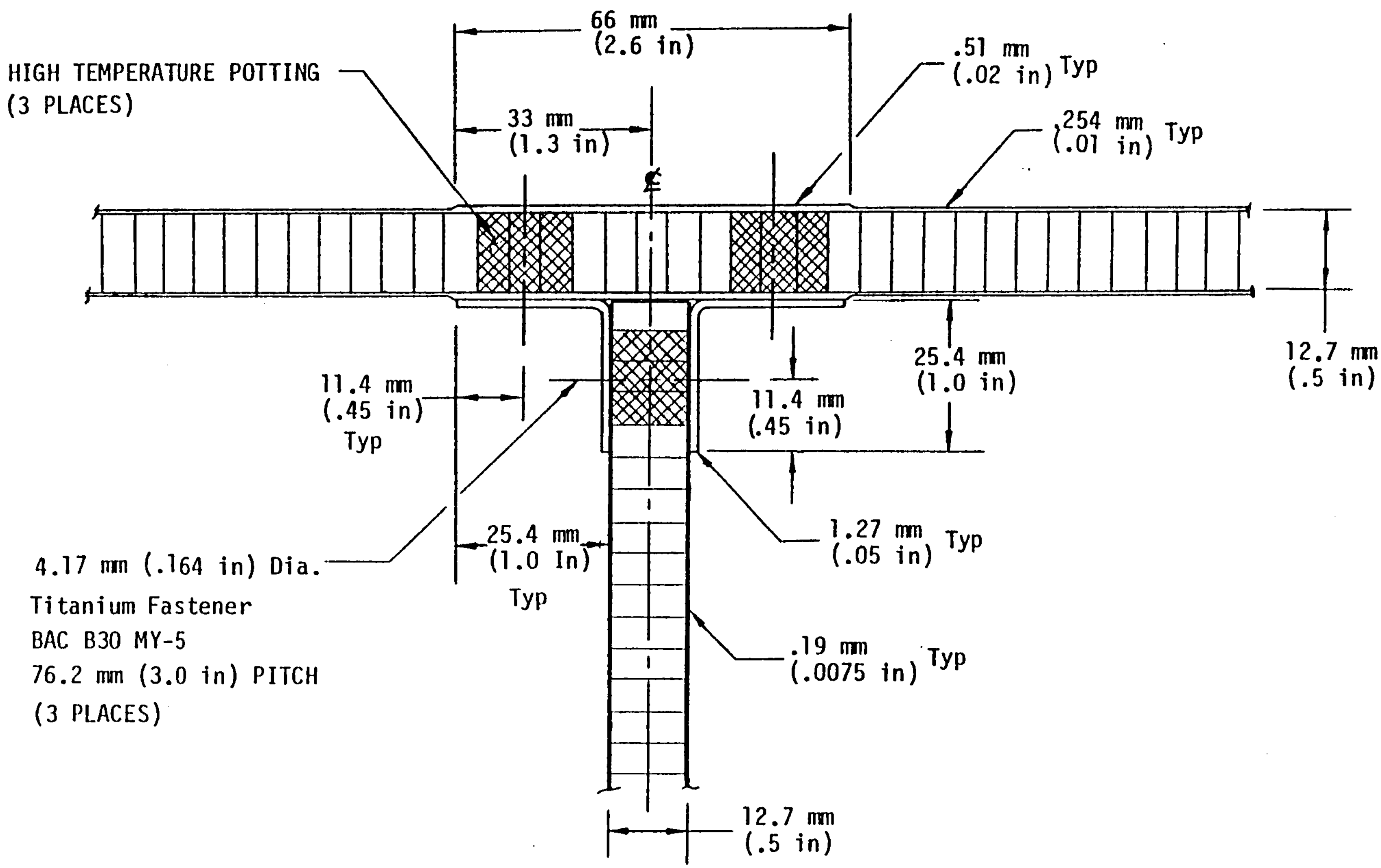


Figure 2-8: Type 4 Bolted Joint Concept

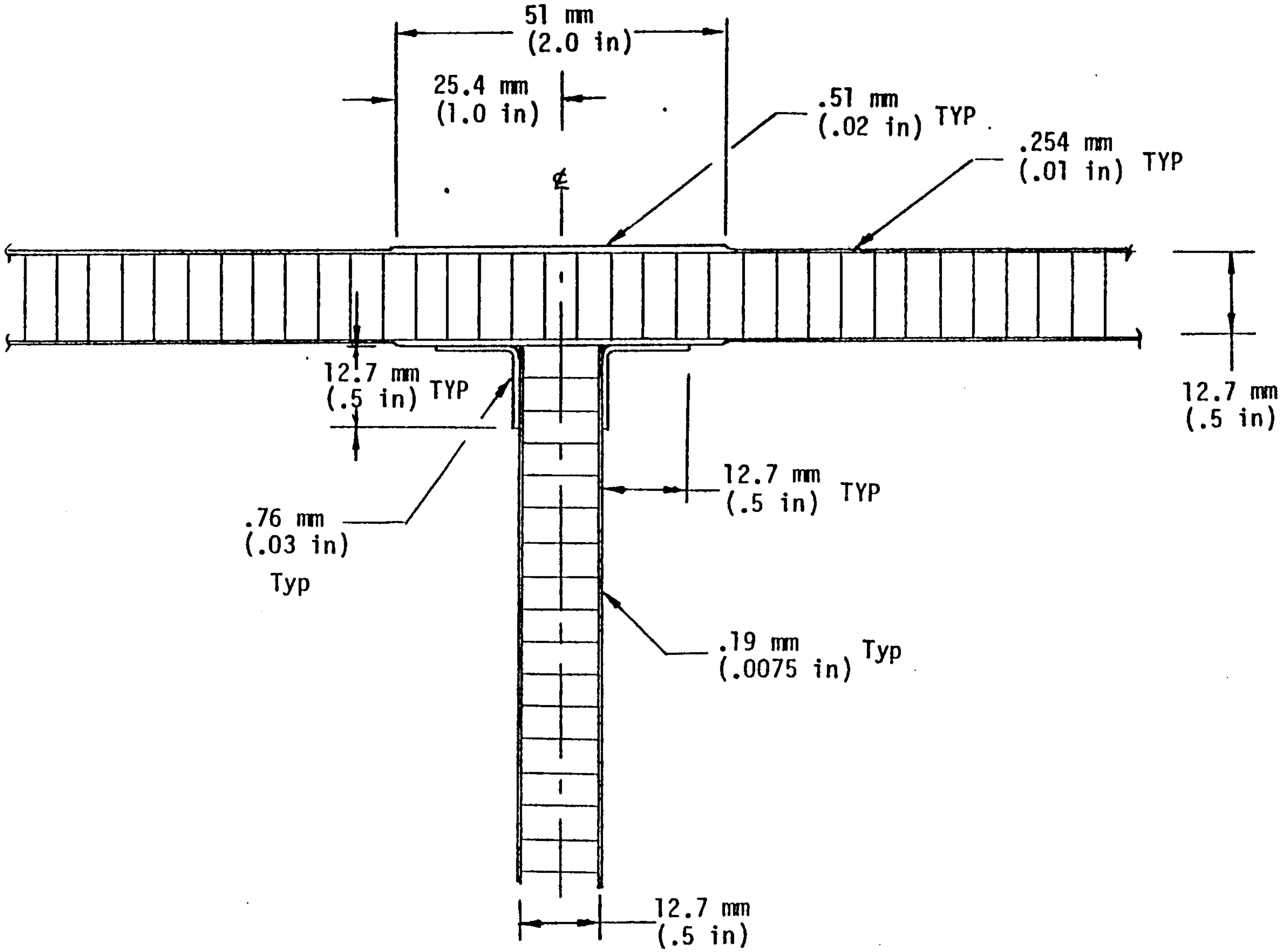


Figure 2-9: Type 4 Bonded Joint Concept

Load introduction/reaction will be accomplished by combinations of core stabilization and externally bonded doublers. While small revisions in doubler thicknesses, lap length, lamina stacking, etc., may be incorporated in finalized designs, these static discriminators represent the results of the screening process reported in References 1 and 5.

2.2 Material and Small Component Characterization

2.2.1 TASK 1.2.1 - Design Allowables

A summary of all design allowables testing completed to date is given in Table 2-1. Tests were on specimens with 51.4% fiber volume; however, the results shown have been normalized to 58% fiber volume which is typical of subsequent material lots used in TASKS 1.2.2 and 2.1.5 specimen fabrication.

TEST TYPE	LAMINATE LAYUP	CONDITION CODE [1]	TEMPERATURE °K(°F)	NUMBER OF SPECIMENS	AVERAGE FAILURE STRESS MPa (ksi)	[2]	AVERAGE MODULUS Ex - GPa (10^6psi)	[3]	POISSON'S RATIO ** μ_{xy}	[4]	SHEAR MODULUS G_{12} - GPa(10^6psi)
TENSION	$0°_{16}$	1	294(70)	3	1441 (209)	6.1	138 (20.1)	0.99			——
		2	294(70)	3	1451 (210)	15.2	146 (21.2)	1.57			
		3	294(70)	5	1396 (202)	7.22	146 (21.2)	0.39	.3272	.024	
		1	561(550)	3	1468 (213)	10.0	142 (20.5)	1.16			——
		2	561(550)	2	1272 (185)	5.19	150 (21.8)	4.54			
		3	561(550)	5	1339 (194)	7.67	112 (21.9)	2.32	.3835	.118	
TENSION	$90°_{30}$	1	294(70)	3	54.5 (7.90)	1.76	9.49 (1.38)	0.07			——
		2	294(70)	3	52.5 (7.61)	0.72	9.65 (1.40)	0.03			
		3	294(70)	5	48.1 (6.98)	0.65	9.26 (1.34)	0.95	.032	.0005	
		1	561(550)	3	23.2 (3.37)	0.44	6.86 (1.00)	0.03			——
		2	561(550)	3	20.7 (3.01)	0.28	6.39 (0.93)	0.09			
		3	561(550)	6	17.1 (2.48)	1.04	6.46 (0.94)	0.13	.0126	.0016	
TENSION	$(0,\pm45,90)_{4s}$	1	294(70)	3	572 (83.5)	2.51	55.6 (8.06)	0.27			——
		2	294(70)	3	539 (78.2)	1.73	56.6 (8.22)	0.18			
		3	294(70)	5	453 (65.7)	2.71	52.6 (7.63)	0.18	.3279	.010	
		1	561(550)	3	544 (78.3)	5.4	50.2 (7.28)	0.07			——
		2	561(550)	3	510 (74.0)	2.12	51.6 (7.49)	0.71			
		3	561(550)	5	424 (61.5)	3.55	53.0 (7.69)	0.73	.3529	0	
COMPRESSION	$(90,\pm45,0)_{4s}$	1	294(70)	4	601 (87.2)	5.65	47.3 (6.86)	0.17	——		——
		2	294(70)	4	578 (83.8)	6.78	43.8 (6.35)	0.34			
		3	294(70)	4	599 (86.9)	7.34	48.3 (7.01)	0.82			
		1	561(550)	4	530 (76.9)	15.7	49.8 (7.22)	0.33	——		——
		2	561(550)	3	466 (67.6)	1.8	46.8 (6.79)	0.18			
		3	561(550)	8	506 (73.3)	8.8	49.1 (7.12)	0.55			
TENSION	$\pm45°_{8s}$	1	294(70)	3	234 (33.9)	0.81	16.7 (2.42)	0.07			
		2	294(70)	4	197 (28.6)	1.5	17.3 (2.51)	0.18	.8989***		5.10 (0.74)***
		3	294(70)	5	173 (25.1)	2.76	15.9 (2.31)	0.15	.1153	.027	7.58(1.1)**
		1	561(550)	2	122 (17.7)	1.15	9.22 (1.34)	0.26			
		2	561(550)	4	116 (16.8)	1.77	10.9 (1.59)	0.18	.8139***		4.63 (0.67)***
		3	561(550)	5	128 (18.5)	1.05	10.7 (1.56)	0.18			

Normalized to 58% Fiber Volume

[1] CONDITION CODE

1 - As cured/postcured

2 - Soaked for 125 hours at 589K (600°F) in a one (1) atmosphere environment (air)

3 - Thermally cycled 125 times in a temperature range from 116K to 589K (-250°F to 600°F) and in a one (1) atmosphere environment (air)

[2] Standard Deviation - ksi

[3] Standard Deviation - 10^6 psi

[4] Standard Deviation

* 4 Specimens

** 2 Specimens

*** 1 Specimen

Table 2-1: Summary of Design Allowable Tests
CELION 3000/PMR 15, (Graphite/Polyimide)

2.2.2 TASK 1.2.2 - Small Specimen Tests

Small specimen tests have been completed to determine bolt bearing and shear out stresses. Tests were run with a 9.53 mm (.375 inch) diameter bolt and a pseudo-isotropic $(0,\pm45,90)_{8S}$ laminate. All tests were run with a constraining washer and the bolt torqued to 7.2 - 8.5 N-m (65-75 in-lbs). A schematic of the test setup is shown in Figure 2-10. Test results are summarized in Figures 2-11, 2-12 and are within the ranges expected. There is some drop in ultimate strength at elevated temperatures; however, there is no significant change in material performance for the three environmental conditionings evaluated.

Tension tests of an integral (co-cured) doubler on a basic $(0,\pm45,90)_{2S}$ face sheet have also been completed. Specimen configuration and test setup are shown in Figure 2-13. The specimen had a constraining washer on only one side and the bolt was torqued to 7.3 - 8.5 N-m (65-75 in-lbs). Test results are summarized in Table 2-2. The specimens failed in net tension through only the basic laminate thickness at the bolt hole. Simultaneously (based on visual observation) there was a tension failure of the basic free field laminate away from the doubler and bolt hole. The free field laminate failure may have been precipitated by a dynamic load transfer when the net tension failure occurred. Free field laminate stresses at failure are slightly lower than the ultimate stresses measured in the design allowables program (see Table 2-1). On the other hand, the net tension stresses in the failed laminate thickness at the bolt hole (it failed only through the free field laminate thickness) are approximately equal to the ultimate failure stress for that laminate without a stress concentration. There may have been an interlaminar shear failure at the laminate and co-cured doubler interface which then propagated to a net tension failure of the basic laminate at the bolt. Additional analyses to evaluate possible load transfer paths are planned. Tests of a bonded doubler are also planned to compare with the co-cured doubler test results.

2.3 TASK 1.3 - Preliminary Evaluation of Attachment Concepts

Joint concepts to be tested under this task are shown in Figures 2-2 through 2-9. Results from these tests will be used to finalize the designs of the specimens for TASK 1.4, static strength and fatigue evaluation tests.

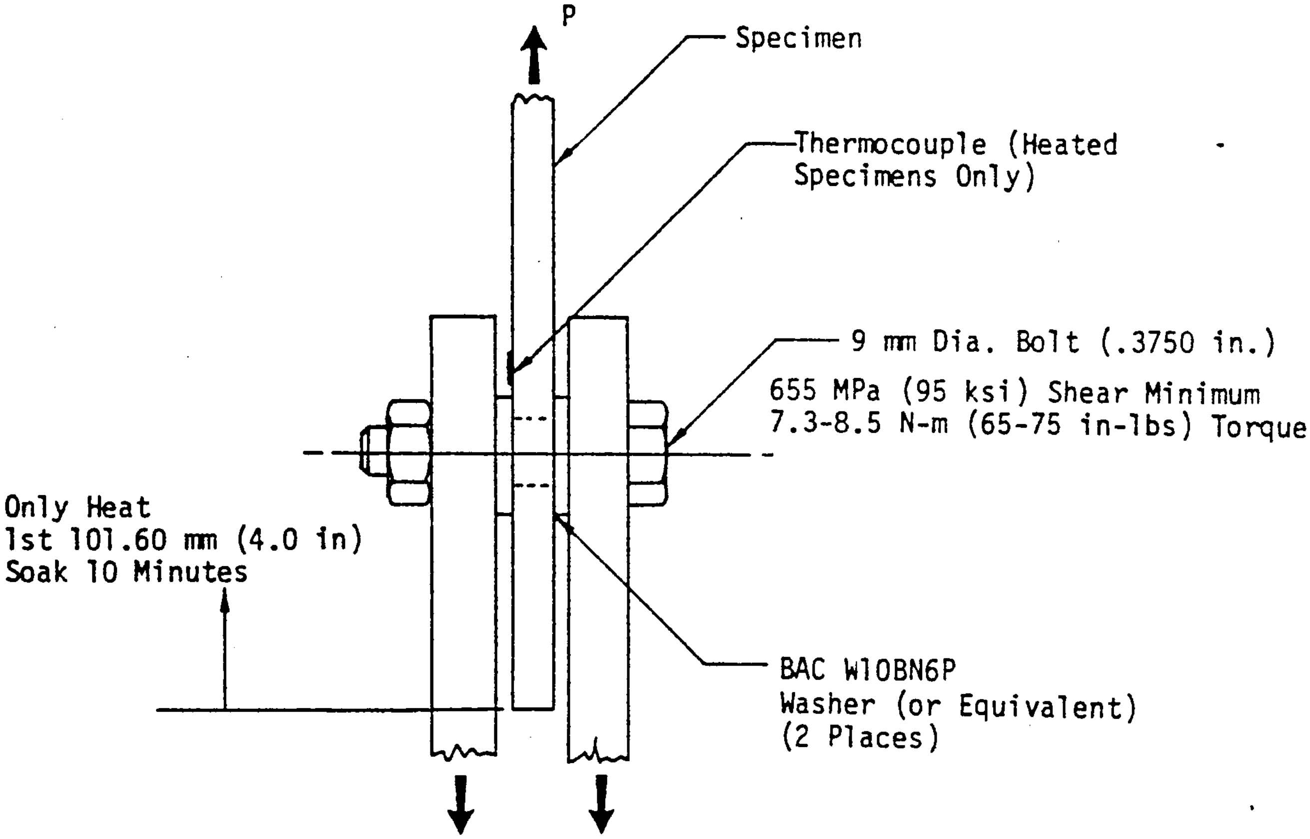


Figure 2-10: Test Setup, Matrix 4A Small Specimen Tests

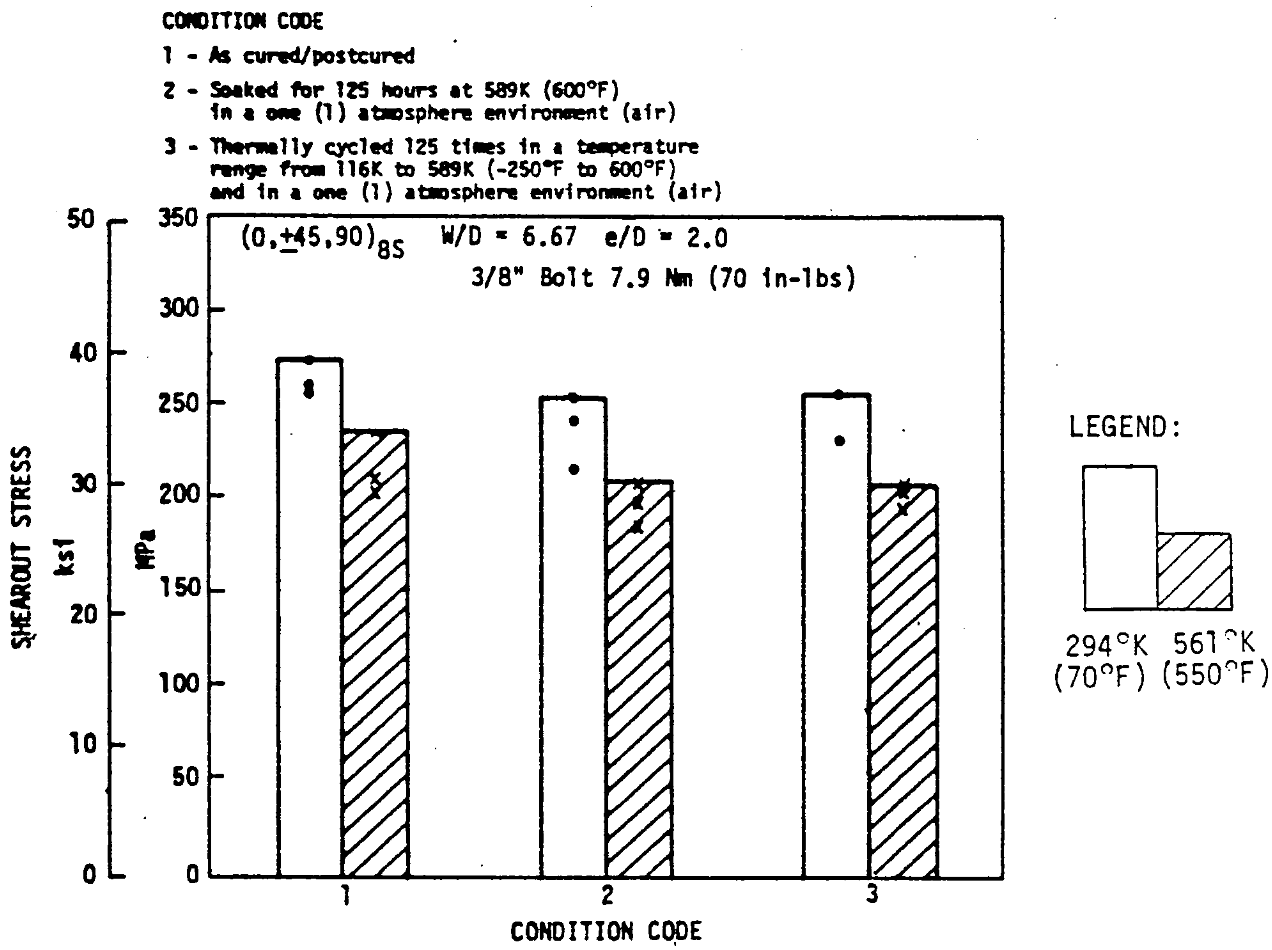


Figure 2-11: Bolt Shearout Test, Matrix 4A

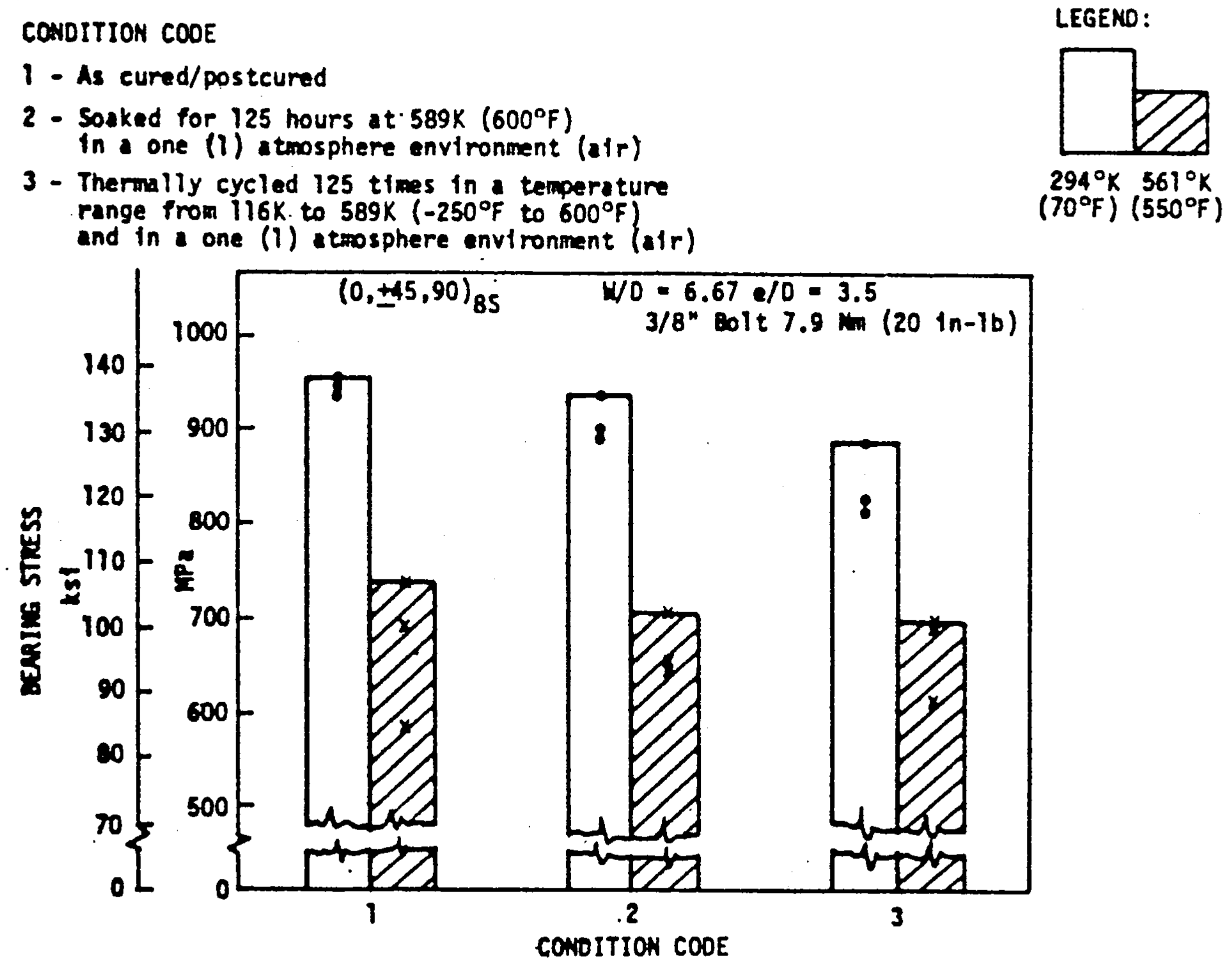


Figure 2-12: Bolt Bearing Test, Matrix 4A

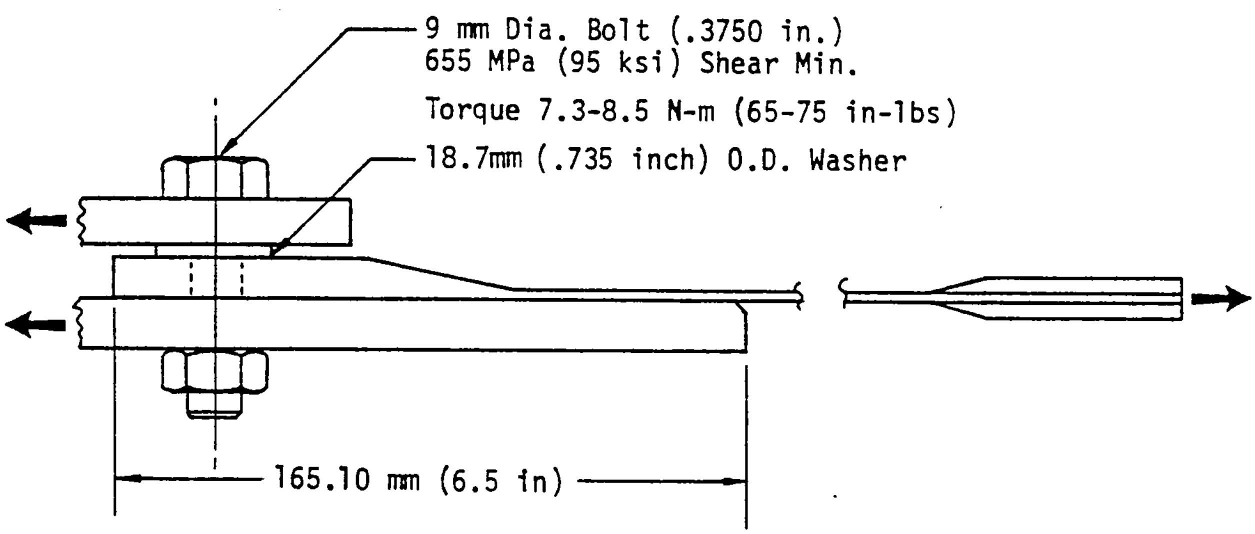


Figure 2-13: Test Setup, Matrix 4B, Tests 1a, 1b, 1c, 2a, 2b, 2c

SPECIMEN NO. *	TEMPERATURE °K (°F)	HOLE DIAMETER mm (inch)	THICKNESS DOUBLER/LAMINATE mm (inch) / mm (inch)	WIDTH mm (inch)	1st YIELD LOAD/BEARING STRESS kN (kip) MPa (ksi)	ULTIMATE FAILURE LOAD kN (kip)	ULTIMATE FAILURE BEARING STRESS (ksi) MPa	ULTIMATE FAILURE NET TENSION STRESS DOUBLER/LAMINATE MPa (ksi)	ULTIMATE FAILURE FREE FIELD LAMINATE STRESS MPa (ksi)
4B-2a-1-1	294 (70)	9.474 (.3730)	2.174/0.569 (.0856/.0224)	47.625 (1.875)	8.05/390.93 (1.81/56.7)	11.48 (2.68)	557.79 (80.9)	138.58/528.83 (20.1/70.7)	423.34 (61.4)
4B-2a-1-2	294 (70)	9.479 (.3732)	2.217/0.559 (.0873/.0220)	47.625 (1.875)	8.59/408.86 (1.93/59.3)	13.21 (2.97)	629.49 (91.3)	156.51/620.53 (22.7/90.1)	496.42 (72.0)
4B-2a-1-3	294 (70)	9.479 (.3732)	2.182/0.546 (.0859/.0215)	47.625 (1.875)	5.74/277.86 (1.29/40.3)	12.14 (2.73)	588.12 (85.3)	145.48/582.61 (21.2/84.5)	466.78 (67.7)
4B-2a-1-4	561 (550)	9.482 (.3733)	2.192/0.564 (.0863/.0222)	47.625 (1.875	6.23/299.92 (1.40/43.5)	10.50 (2.36)	506.08 (73.4)	125.48/504.00 (18.2/73.1)	403.34 (58.5)
4B-2a-1-5	561 (550)	9.484 (.3734)	2.306/0.549 (.0908/.0216)	47.625 (1.875)	6.14/281.31 (1.38/40.8)	9.61 (2.16)	463.33 (67.2)	115.15/459.19 (16.7/66.6)	367.49 (53.3)
4B-2a-1-6	561 (550)	9.469 (.3728)	2.205/0.584 (.0868/.0230)	47.625 (1.875)	5.34/255.80 (1.20/37.1)	9.96 (2.24)	477.81 (69.3)	118.59/446.78 (17.2/64.8)	357.84 (51.9)
4B-2b-2-1	294 (70)	9.528 (.3751)	2.230/0.544 (.0878/.0214)	47.625 (1.875)	5.38/255.10 (1.21/37.0)	10.14 (2.28)	480.56 (69.7)	119.28/489.53 (17.3/71.0)	391.62 (56.8)
4B-2b-2-2	294 (70)	9.500 (.3740)	2.179/0.541 (.0858/.0213)	47.625 (1.875)	2.89/139.96 (0.65/20.3)	9.25 (2.08)	448.85 (65.1)	171.70/448.85 (16.2/65.1)	359.22 (52.1)
4B-2b-2-3	294 (70)	9.520 (.3748)	2.156/0.533 (.0849/.0210)	47.625 (1.875)	6.14/300.61 (1.38/43.6)	11.83 (2.66)	579.85 (84.1)	144.10/617.08 (20.9/89.5)	466.08 (67.6)
4B-2b-2-4	561 (550)	9.512 (.3745)	2.240/0.541 (.0882/.0213)	47.625 (1.875)	ND/ND	10.28 (2.31)	484.70 (70.3)	120.66/498.49 (17.5/72.3)	398.52 (57.8)
4B-2b-2-5	561 (550)	9.502 (.3741)	2.136/0.569 (.0841/.0224)	47.625 (1.875)	NON-APPARENT	10.10 (2.27)	499.18 (72.4)	124.11/465.40 (18.0/67.5)	372.32 (54.0)
4B-2b-2-6	561 (550)	9.505 (.3742)	2.151/0.544 (.0847/.0214)	47.625 (1.875)	6.51/321.30 (1.47/46.6)	10.32 (2.32)	506.76 (73.5)	126.17/498.50 (18.3/72.3)	398.52 (57.8)

Table 2-2: Matrix 4B, Small Specimens - Integral Doubler

$e/D = 2.0$, $W/D = 6.67$

[2] Bolt Diameter = 9.465 mm (0.3726 in)

* CONDITION CODE

1 - As cured/postcured

2 - Soaked for 125 hours at 589K (600°F) in a one (1) atmosphere environment (air)

3 - Thermally cycled 125 times in a temperature range from 116K to 589K (-250°F to 600°F) and in a one (1) atmosphere environment (air)

SECTION 3.0

TASK 2 BONDED JOINTS

3.1 TASK 2.1 - Standard Bonded Joints

This task includes the analysis, fabrication and static strength determination of several standard bonded joint configurations. The theoretical influence of geometric and material parameters are being investigated and a test/analysis correlation performed to determine the relative efficiencies of the various joint configurations. The relationships of the sub-task activities are shown in Figure 3-1.

This section discusses ancillary laminate and adhesive tests, joint specimen fabrication and NDE, and joint test program.

3.1.1 TASK 2.1.3 - Ancillary Laminate and Adhesive Test

Twenty-four titanium "thick adherend" adhesive test specimens have been shipped to Dr. J. R. Vinson, University of Delaware. Twelve specimens are the cured/post-cured condition, and twelve are thermally aged 125 hrs. at 589K (600°F). Three specimens of each will be run at 116°K (-250°F), 294°K (70°F), and 561°K (550°F). The room temperature tests are scheduled to start the first week of May with the elevated temperature and cold tests to follow.

3.1.2 Task 2.1.4 - Joint Specimen Fabrication and NDE

Material lots 2W4651 and 3W2020 have been fabricated into panels. Quality Control data for these two lots are summarized in Table 3-1.

A summary of panel and specimen fabrication status is given in Table 3-2. Fabrication and conditioning of the remaining specimens is in progress.

3.1.3 TASK 2.1.5 - Standard Joint Test

The first series of standard joint specimens has been delivered to the test labs, and testing has been started. Results will be reported as they become available.

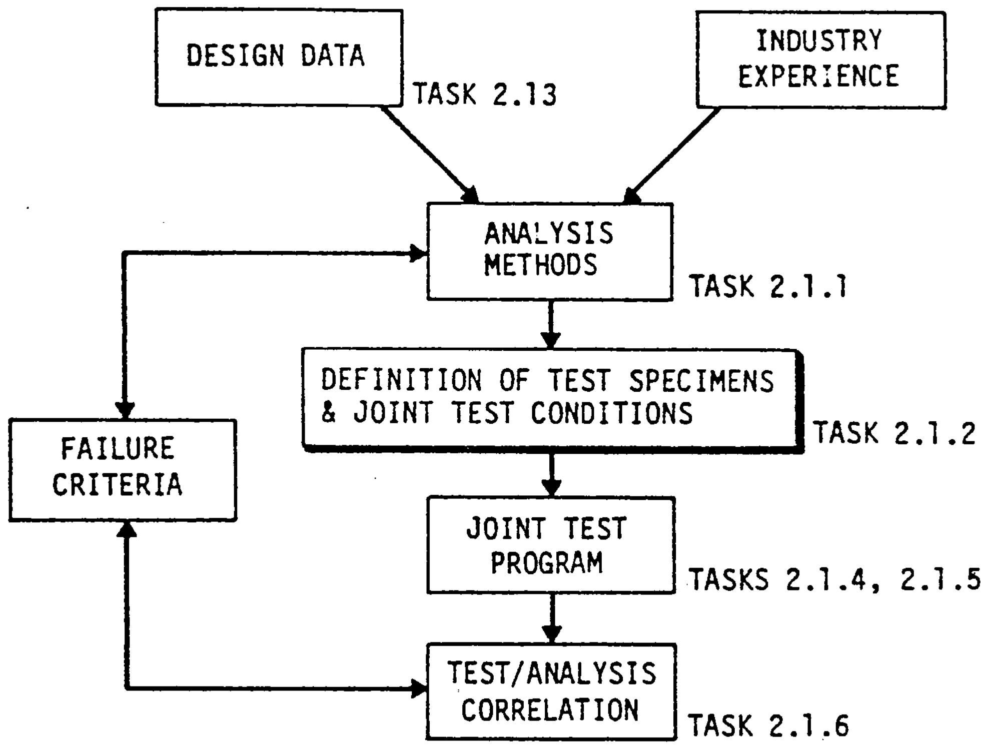


Figure 3-1: Task 2 Bonded Joint Subtasks

Table 3-1: Quality Control Test Panel Properties (Averaged)

Property		Requirement	LOT 2W4561			LOT 3W2020			
			Roll 2	Roll 3	Roll 2 Revised	Roll 1	Roll 2	Roll 3	Roll 3 Revised
Fiber Volume, %		58 ± 2	59.5	53.3	59.5	58.0	56.0	60.8	60.1
Resin Content, %		30 +3	32.7	38.5	32.7	34.2	36.3	31.1	32.7
Specific Gravity g/cc		1.54	1.58	1.54	1.57	1.57	1.57	1.57	1.59
Void Content, %		<1	0.5	1.2	1.4	<1	<1	1.7	<1
Flexural Strength MPa (ksi)	At Ambient	1515 (220)	1558 (226)	1475 (214)	[1]	1579 (229	1220 (177)	1310 (190)	1413 (205)
	At 589K (600°F)	757 (110)	780 (116)	738 (107)	772 (112)	869 (126)	772 (112)	793 (115)	979 (142)
	Aged, at 589K (600°F)	757 (110)	855 (124)	924 (134)	813 (118)	993 (144)	738 (107)	862 (125)	[1]
Flexural Modulus GPa (msi)	At Ambient	117 (17)	119 (17.2)	116.5 (16.9)	[1]	120.6 (17.5)	115.8 (16.8)	108.2 (15.7)	115.8 (16.8)
	At 589K (600°F)	103 (15)	103.4 (15.0)	103.4 (15.0)	107.5 (15.6)	111.7 (16.2)	107.5 (15.6)	118 (17.1)	102 (14.8)
	Aged, at 589K (600°F)	103 (15)	108.2 (15.7)	107.6 (15.6)	104.8 (15.2)	111 (16.1)	97.9 (14.2)	105 (15.0)	[1]
Short Beam Shear Strength MPa (ksi)	At Ambient	96 (14)	88.2 (12.8)	87.5 (12.7)	110.3 (16.0)	95.8 (13.9)	93.8 (13.6)	94.5 (13.7)	106.2 (15.0)
	At 589K (600°F)	41 (6)	40.1 (6.4)	45.5 (6.6)	58.6 (8.5)	65.5 (9.5)	51.0 (7.4)	56.5 (8.2)	57.2 (8.3)
	Aged, at 589K (600°F)	41 (6)	44.8 (6.5)	46.2 (6.7)	62.0 (9.0)	55.2 (8.0)	53.8 (7.8)	57.9 (8.4)	[1]

[1] Test data not available

Revised-Lowered hold temperature during cure from 522°K (480°F) to 505°K (450°F)

TEST	MATRIX NO. [1]	NO. OF PANELS		NO. OF SPECIMENS	
		Req'd	Made	Req'd	Made
DESIGN ALLOWABLES	1	16	16	226	145
ANCILLARY ADHESIVE	2	NA	NA	84	36
STANDARD JOINTS	3A	18	18	126	24
	3B	3	3	54	0
	3C	2	2	6	0
	3D	44	44	192	102
	3E	6	6	54	0
	3F	4	4	12	0
	3G	Integral Layup	-	54	0
SMALL SPECIMENS	4A	12	12	72	35
	4B	21	21	60	12
	4C	27	27	72	0

Table 3-2: Specimen Fabrication and Test Summary
GR/PI Joint Contract NAS1-15644

NA Not Applicable

[1] Matrices defined in Quarterly Progress Report #3 (CR-159110) except Matrix 4C which is in Quarterly Progress Report #4 (CR-1159111).

SECTION 4.0

CONCLUDING REMARKS

During this reporting period the principal program activities dealt with selecting joint concepts for the static discriminator tests, fabrication of "Thick Adherend", "Standard Joint" and "Small Specimen" test specimens, testing of the bolt bearing, shear out and integral doubler specimens and starting of standard joint testing.

Results of testing discussed in this report have led to the following conclusion:

- Aging and thermal cycling does not significantly change the ultimate bearing and shear-out stress of a $(0,\pm45,90)_{8S}$ laminate.

REFERENCES

1. Arnquist, J. L. and Skoumal, D. E., "Design, Fabrication and Test of Graphite/Polyimide Joints and Attachments for Advanced Aerospace Vehicles", Quarterly Progress Report #3, Contract NAS1-15644, NASA CR-159110, October 15, 1979.

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3. Ishai, O. and Gali, S., "Two-Dimensional Interlaminar Stress Distribution Within the Adhesive Layer of a Symmetrical Doubler Model", Journal of Adhesion, 1977, Vol. 8, pp. 301-312.

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